High Cycle Fatigue Analyses of Heavy Duty Diesel Engines

M. Erdogan, Y. Yazicioglu, S. Erpolat

OUTLINE

• Ford Otosan Product Development
• Use of Femfat in HD Engine Design
• Durability Assessment of Cyl Heads at FO
• Conclusion
FORD OTOSAN QUICK FACTS

- A Joint Venture of Ford Motor Co. (41% Ford, 41% Koç Group)
- Vehicle, Engine & Powertrain Plants: Gölcük & İnönü
- Parts & Distribution Center: Kartal
- Engineering Center: Gebze & Kocaeli
- 10000 employees
- 1300+ PD personnel
- Revenue of 5.5 Billion USD (2012)
High Cycle Fatigue in ICE

- HCF is one of the most critical design concerns in engine design due to combustion and inertial loading.

- FO prefers Femfat for the analyses of following components:
  - Cylinder Head
  - Cylinder Block
  - Piston
  - Connecting Rod
  - Crankshaft
  - Camshaft
  - Critical 5C bolts

[Ref: Bick, W et al. “Light weight engine concepts for 200 bar peak firing pressure”. 5th CGI Machining Workshop. Darmstadt, Germany, Sept 2003]
CYLINDER HEAD LOADING

- Low Cycle Fatigue
- High Cycle Fatigue

CYLINDER HEAD DURABILITY ASSESSMENT

- Ford Motor Co. and Ford Otosan have a very long experience of cylinder head analyses.
- FO currently uses commercially available software Femfat for HCF analyses and Zebulon for TMF assessment for HD cylinder heads.

- Conjugate CFD Analysis
- Metal Temperature Distribution
- Elastic/Plastic Structural FE Modelling
- Hotlife
- Femfat TransMAX
- Residual Stress Analysis
- Residual Stress Distribution
- High Cycle Fatigue (HCF) Analysis
- Low Cycle Fatigue (LCF) Analysis

Cylinder Head Methodology for LD Applications
CYLINDER HEAD DURABILITY ASSESSMENT

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Cylinder Head Methodology for HD Applications

FE MODEL

- Block Head Compound Model incorporates cylinder head, block, gasket, main bolts, valve seat inserts, valve guides, injectors, injector clamp, etc.
- Several design aspects can be addressed by this extensive model:
  - Temperature distribution
  - HCF/LCF of cylinder head
  - HCF of liner collar
  - Gasket sealing
  - Bore distortion
  - Valve seat distortion
  - Miscellaneous
HEAT TRANSFER ANALYSES

- Ford Otosan’s cylinder head analysis is based on conjugate heat transfer analysis.
- Decoupled approach is also used to make use of AVL boiling subroutine, i.e. on Bubble Departure Lift-off (BDL) method.

Conjugate Approach

Conjugate Cooling Jacket CFD

Map Solid Thermal B.C

FEA Thermal and Structural Analysis

Input-B.C
1. Cooling System 1D
2. Experiment
3. Cooling Jacket CFD
4. 1D Gas Dynamic Code

BOUNDARY CONDITIONS

Inputs

- Interference between Cylinder Head and Valve Seat/Guide
- Contact definitions between Head/Gasket/Block, Head Bolt & Injector Clamp Loading, etc.
- Metal Temperature Distribution mapped to Head&Block Assembly
- Peak Firing Pressure (PFP)

FE Modelling

- Valve Seat/Guide Press Fit
- Assembly Loading
- Thermal Loading (Steady State)
- Gas Pressure Loading
- HCF Analysis

Temperature dependant fatigue material behaviour and Femfat Model for Cyl.Head, Metal temperature distribution
LOADING HISTORY

• In a 6-cylinder engine, 21 different combinations of loading should be assessed in Femfat BASIC. Femfat TransMAX reduces the number of Femfat runs to ‘one’.

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<thead>
<tr>
<th>Femfat BASIC runs</th>
<th>Femfat TransMAX runs</th>
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<tr>
<td>AT00-ATG1</td>
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21 Femfat BASIC runs = A single Femfat TransMAX run

RESULTS

• Femfat was effectively used to ensure fatigue durability and fix critical issues in cylinder head and engine block.
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TMF MATERIAL CHARACTERIZATION
CONCLUSION

- Femfat is a very effective tool to perform durability assessment of critical engine components.

- Femfat allows the incorporation of residual stresses to fatigue analyses as well as several fatigue influence factors. Femfat TransMAX is a convenient tool to combine several loading conditions.

- This aspects make Femfat TransMAX an ideal tool for the fatigue assessment of cylinder heads and blocks.

- FO is currently investing on constructing fatigue test rigs as well as accurate prediction of residual stresses and their incorporation into fatigue analyses to increase the robustness of HCF assessment.